Observation of Ultra High Energy Cosmic Rays in cloudy conditions by the JEM-EUSO Space Observatory

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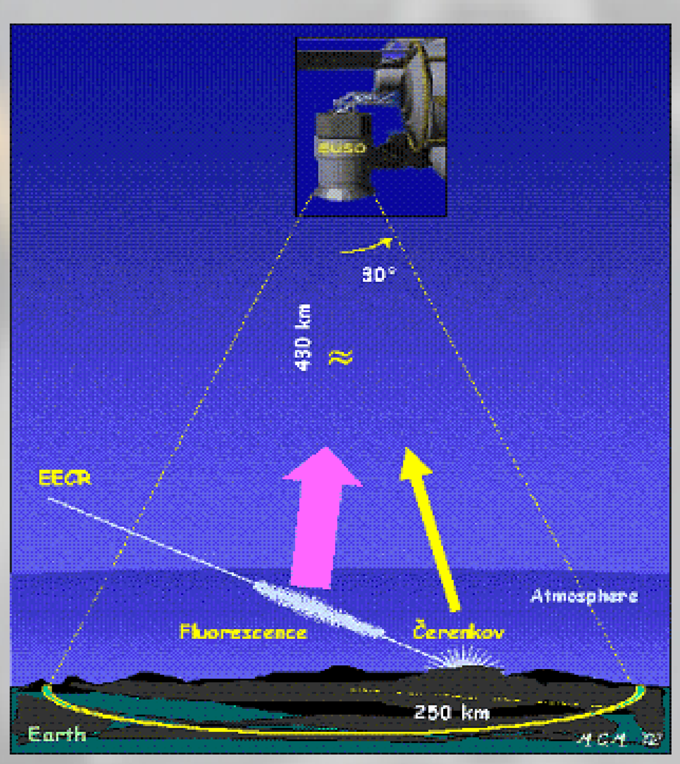
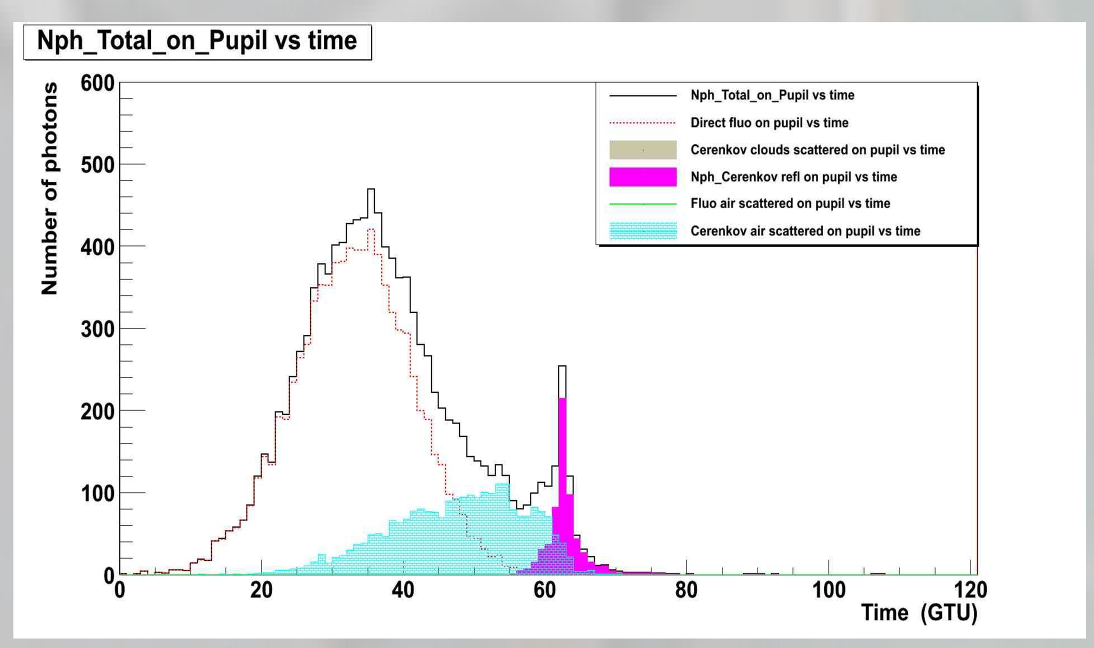
Abstract: JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is a space-based experiment that will be located at the International Space Station aming to identify origin sources by detecting UHECRs at large statistics. It will use the atmosphere as a huge detector. Therefore, it is important to study how the presence of clouds will affect the detected signal of those UHECR. In the present work we simulated the EAS observation by the JEM-EUSO telescope to evaluated the impact of the clouds in EAS.

Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is the space-based Ultra-High Energy Cosmic Ray (UHECR) observatory to detect extensive air showers (EASs) monitoring night atomosphere. Apart from postanalysis using Atmospheric Monitoring System on the telescope, the EECR observation is continuosly operated throughout various atmospheric conditions including the presence of clouds. Unlike ground-base experiment, signals from EAS through such condtions are observable thanks to unique location of the observatory on the orbit. In the present work, we studied the effect of clouds to EAS signals and to the aperture for UHECR observation.



Clear sky



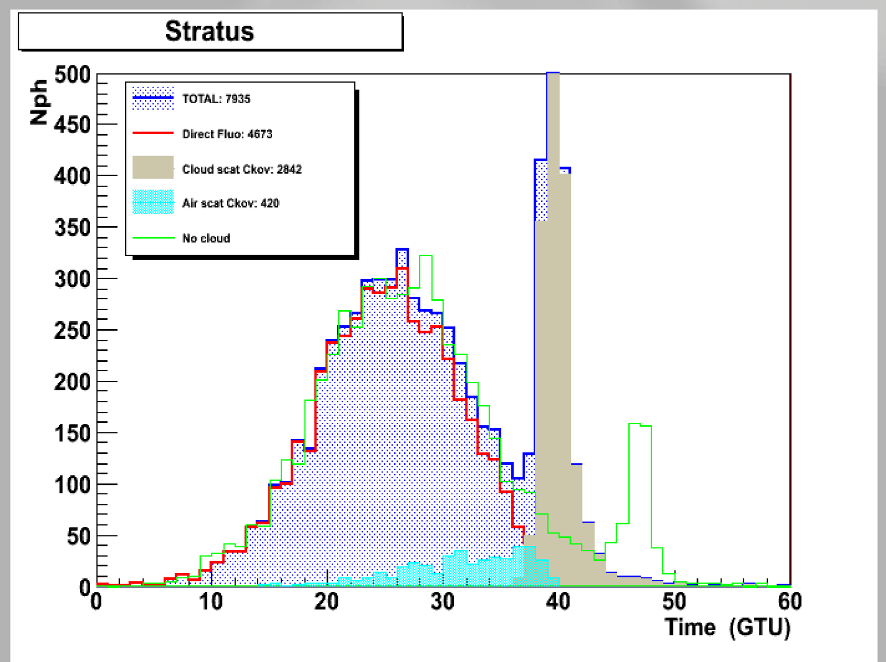
Observation principle of JEM-EUSO

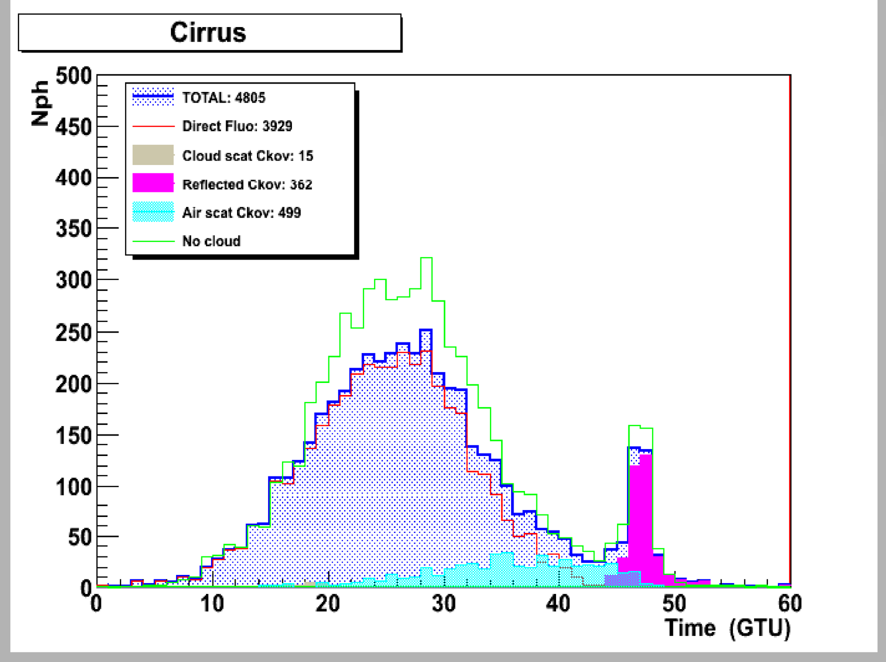
The principle of the space-based observation is based on the measurement of fluorescence light and in part Cherenkov light reflected from the Earth's surface (left panel). The light curve (time profile of arrival photon to telescope pupil) for the typical EAS (10^{20}eV from 60 degrees zenith angle) is shown in the right panel in unit of GTU (gate time unit = 2.5 microseconds). The main part of light curve is constructed with direct fluorescence photons and is followed by the reflected Cherenkov light. In this example, the clear sky case is assumed and therefore the latter represents the reflection signal from the Earth's surface

Simulation for EAS profile in cloudy condition

ESAF (Euso Simulation and Analysis Framework) is used to estimate the efficiency of EAS observation and the behaviour of the signal produced by EAS in cloudy condtions. The Impact of the the cloud distribution has been taken into account as well. Simulations have been performed considering the cloud as a uniform layer, whose characteristics are optical depth τ and cloud-top altitude *H*c. The physical thickness of the cloud has been considered to be 1km for every case. Also, background is considered as constant.

The right panels demonstrates the effect to observed EAS light curve in the presence of stratus (top) and cirrus (bottom). In the simulations, these clouds are modeled with combinations of τ and *H*c as 5 and 2.5km and 0.05 and 10 km, respecitively. In each case, the light curve expected for the clear sky is shown from comparison.





For stratus-like clouds with large τ at lower altitudes, most of signals from EAS are observed without attenuation when the altitude of the cloud is well below the altitude of EAS development, Such clouds also produce a very intense reflected Cherenkov signals and the detected signal is even better than that for the clear sky case. This will enhance the better capablity of triggering and reconstruction for EAS geometry.

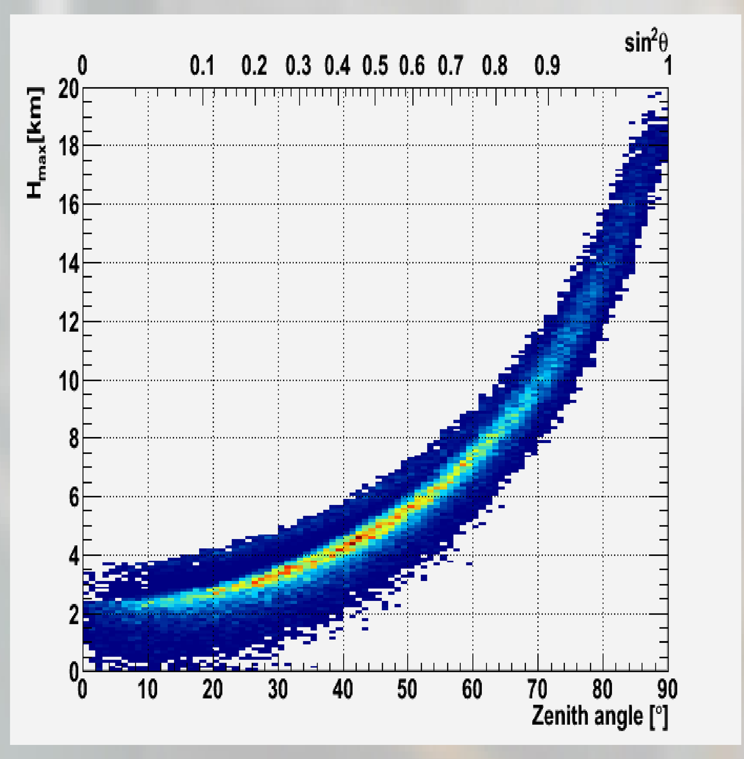
For cirrus-like cloud at higher altitudes, signals from EAS are attenuated according to the optical depth, while the shower image and its time evolution will allow the arrival direction analysis.

Impact on trigger efficiency

In order to evaluate the impact on the trigger efficiency (ratio of trigger apeture to saturated fiducial aperture for clear sky condition) due to the cloud presence, we simulated a large sample of EAS events on various cloud conditions. The set of key parameters is as follows:

- •Primary UHECR: proton
- •Primary energy [eV]: 3×10^{19}—10^{21}
- •Zenith angles: 0—90 degrees
- •Optical depth: 0.05, 0.5, 1.5 and 5
- •Cloud-top altitude: 2.5, 5, 7.5 and 10 km
- •Physical cloud thickness: 1km
- •JEM-EUSO altitude: 400 km
- •Operation mode: Nadir mode

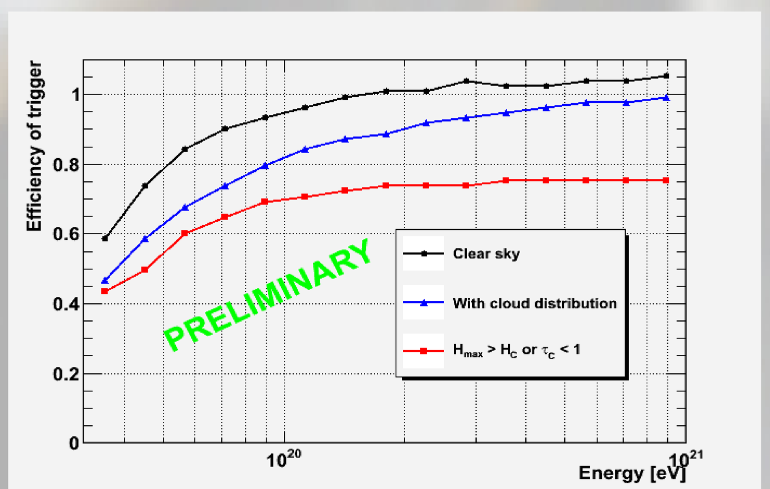
For each condition, 100,000 events were simulated with a spectrum of $dN / dE \propto E^{-1}$. The same simulation for clear sky case was also carried out for comparison.



In order to evaluate the impact on the trigger efficiency due to the cloud presence, the altitude of the maximum of EAS development (*H*max) is shown as a function of zenith angle. Note that in energy range of interest the depth of EAS development (*X*max) only varies by ~100 g/cm^2 and therefore the *H*max is dominantly determined by the zenith angle. From this plot, for example, *H*max > ~7km for 60 degress EAS.

For the simulated conditions of clouds, the average trigger effiency is summarised in the follwoing table for UHECR events above 5.5×10^{19} eV as a ratio of trigger efficiency to the clear sky case (*cloud impact*) and is ~82% very little dependant of spectrum (E^{-3} is assumed herein). The probability of the presence of various type of clouds have been studied in Garino et al in the present conference. The convolution of cloud presence probablity and *cloud impact* yields the overall trigger efficiency as shown in the right panel. This panel also shows further requirement of Hmax above optically thick cloud (τ>1) or clouds with τ<1. These conditions allow observation of the maximum of the shower. In this case, the cloud impact is ~70% indenpendant of energy which is interepreted by the geometrical relations between Hmax and typical cloud altitudes.

E>5.5x10^{19}eV PRELIMINARY	Cloud-top altitude [km] 2.5	5	7.5	10
OD = 5	88%	66%	37%	18%
OD = 1.5	89%	69%	43%	26%
OD = 0.5	88%	82%	74%	70%
OD = 0.05	90%	89%	89%	90%



Conclusion

The effect of clouds to EAS observation by JEM-EUSO were studied using ESAF code. The presence of low-altitude stratus-like clouds may enhance capability of detection and reconstruction of EAS. Cirrus-like clouds reduce just slightly the signal from EAS.Considering all conditions according to the study of Garino et al., about 80% of the showers produced will be detected. For more than 70% of triggered EAS, cloud effect is limited as the maxima of EAS development are observable above optical thick clouds or through optically thin clouds.

References

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